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AN ANALYSIS OF MECHANICAL SHAKING IN
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Fabric air filters are cleaned by a variety of techniques, most of which involve some method of vibrating the dust cake from the fabric. The most common technique in this class is that of mechanical shaking. While little quantitative information is available relative to the variables of shaking, work in this area suggests that such information could be used to optimize the effectiveness of the cleaning operation in many instances.

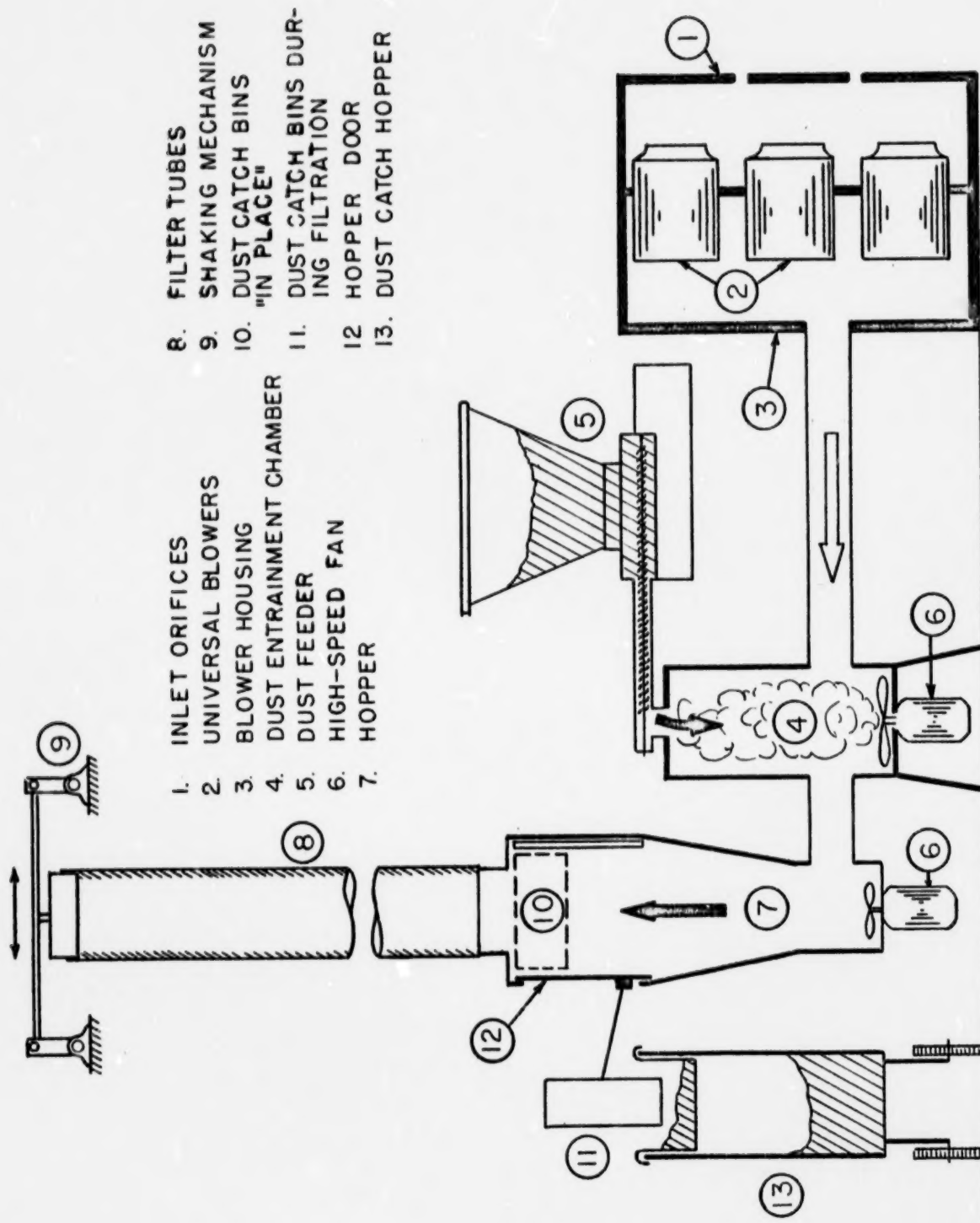
It is the purpose of this paper to show the influence of shaker amplitude and shaker frequency, and the effect of cleaning time on filter performance. Other factors which might alter cleaning effectiveness by influencing the transmission of motion, such as tube geometry, filter fabric, shaking direction, etc., were held constant for most of the experiments. Filter performance was quantitatively analyzed in terms of residual filter drag and filter capacity, which were considered as basic response variables and are defined as follows:

Residual filter drag is that property of the dust-fabric combination after cleaning which expresses its resistance to flow. It is measured as the ratio of filter pressure differential to filter velocity, and is analogous to resistance in an electrical sense. It is important as a response variable in that it is a property of the system and also because it is directly related to fan performance and power requirements. More detailed discussion of this property can be found in the literature.⁽¹⁾⁽²⁾

Filter capacity is the weight of dust per unit of cloth area which can be collected without exceeding some maximum filter drag. It is, therefore, a measure of cleaning effectiveness.

Equipment and Test Procedure

The two-bag pilot-plant assembly used for these experiments is schematically shown in Figure 1. Before operation for any test, this unit was cleaned, new bags were installed and a fresh supply of dust charged to the dust feeder. Dust was mixed with the inlet air in the primary entrainment chamber and maintained in suspension by the secondary chamber. Because of the two entrainment chambers used, essentially all the dust fed into the system was deposited on the filters. When a pre-determined maximum filter drag (terminal drag) was reached, the unit was shut down, dust-catch bins were moved into place below the filters, and the tubes were shaken by a horizontal shaking mechanism. The use of dust-catch bins directly below the filters allowed for an analysis of the dust catch per cycle and eliminated problems of dust re-entrainment at the start of a cycle. Filtration-cleaning cycles were automatically controlled to permit overnight operation and to provide consistency in test procedure. The filters were conditioned for at least twenty complete cycles before data were taken, so that the results reflect equilibrium conditions. The filter tubes were 6 inches in diameter by 60 inches in length and were fabricated of a standard cotton sateen (96 warp x 60 woof, 9.7 oz/yd²). They were clamped to a bag cap which was rigidly connected to the shaking mechanism. The technique used to install the filters was the same from test to test. The condition selected was one of zero tension and zero slack.



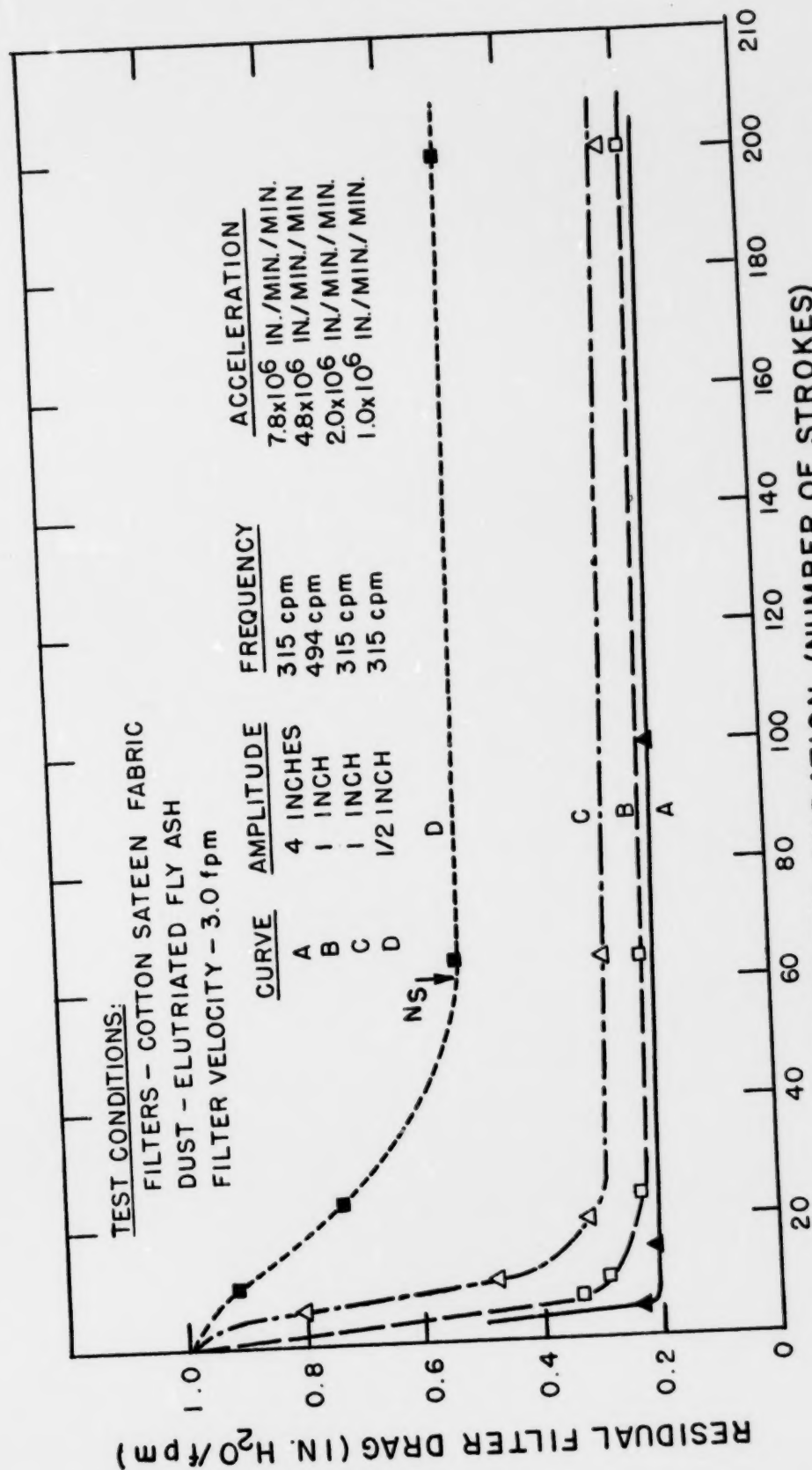
SCHEMATIC DRAWING OF TWO BAG-TEST UNIT

FIGURE 1

The major test dust used was a fly-ash material elutriated to less than 7 microns and having a geometric mean diameter, by weight, of 3.2 microns with a standard geometric deviation of 1.8 microns. A large quantity of the material was prepared and carefully blended before distribution to smaller supply drums. Dust for each experiment was randomly selected from these smaller supplies before each test.

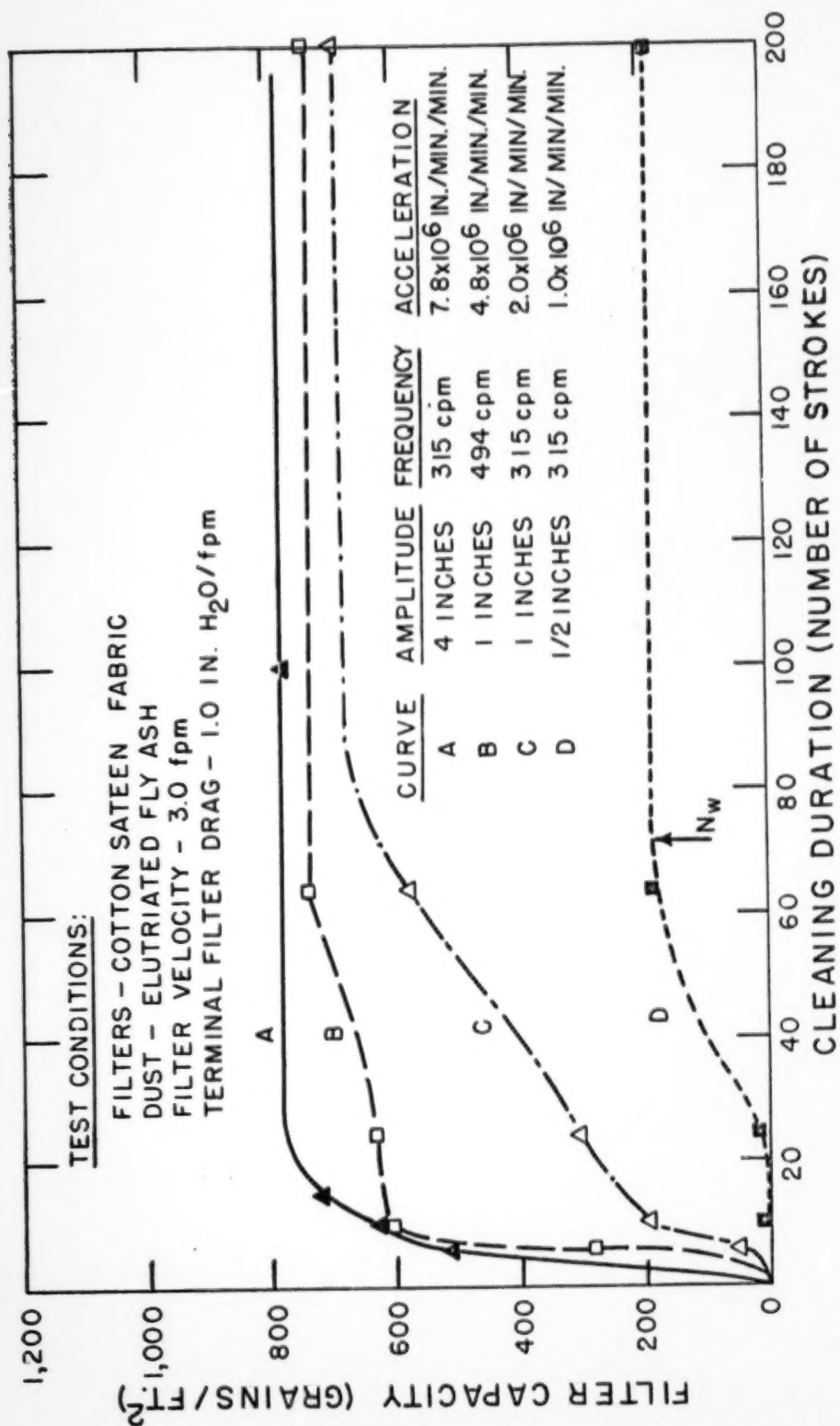
Cleaning Duration

The first relationships studied concerned the effect of cleaning duration (number of shaking strokes) on the response variables, residual drag, and filter capacity. Typical results are shown in Figures 2 and 3. They substantiate prior research results⁽³⁾⁽⁴⁾ which indicate that the initial cleaning strokes accomplish the most work, and they show that a limit exists beyond which increased "cleaning" duration will not substantially increase capacity nor decrease residual drag. The number of strokes required to approximate minimum drag is designated N_g and is shown on Curve D, Figure 2. Physically, N_g was the number of strokes required to create significant discontinuities in the dust mass structure so that the effective drag was at a practical minimum because of low resistance areas: Observations indicate that N_g was approximately reached when motion was developed over the entire filter. Subsequent filtration on such a surface was analogous to filtration on a reduced area so that the rate of drag increase was high and the weight of dust collected before a predetermined drag level was reached was low. Maximum capacity was reached when the discontinuities in the dust cake were minimized for a particular shake. As a result, cleaning durations required to approximate maximum capacity were greater than those required to approximate minimum drag. The number of strokes required to approach maximum capacity is termed N_w as shown for Curve D in Figure 3.



**EFFECT OF CLEANING DURATION ON RESIDUAL FILTER DRAG
 FOR SEVERAL SHAKING CONDITIONS**

FIGURE 2



EFFECT OF CLEANING DURATION ON FILTER CAPACITY
 FOR SEVERAL SHAKING CONDITIONS

FIGURE 3

Applied Motion

It can be seen in Figures 2 and 3 that the limiting values associated with the response variables are dependent on some combination of amplitude and frequency. The investigations show a correlation between the maximum acceleration produced in the course of the harmonic shaking stroke and the limiting values of the response variables. This acceleration can be calculated from the equation

$$a = 2\pi^2 (1) r^2 \quad (1)$$

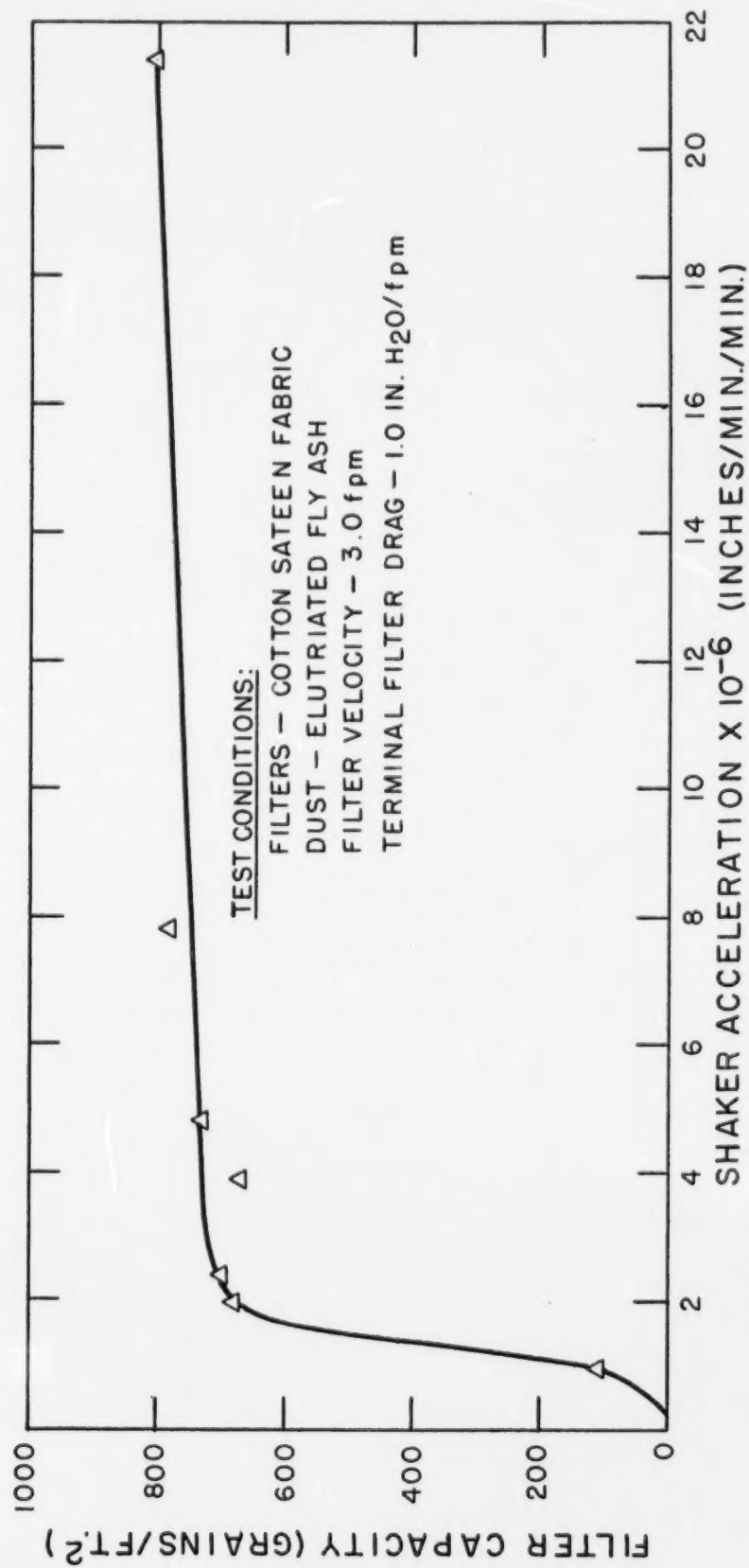
where a = maximum acceleration in harmonic motion
(in/min/min)

1 = shaker amplitude (inches)

f = shaker frequency (strokes per min)

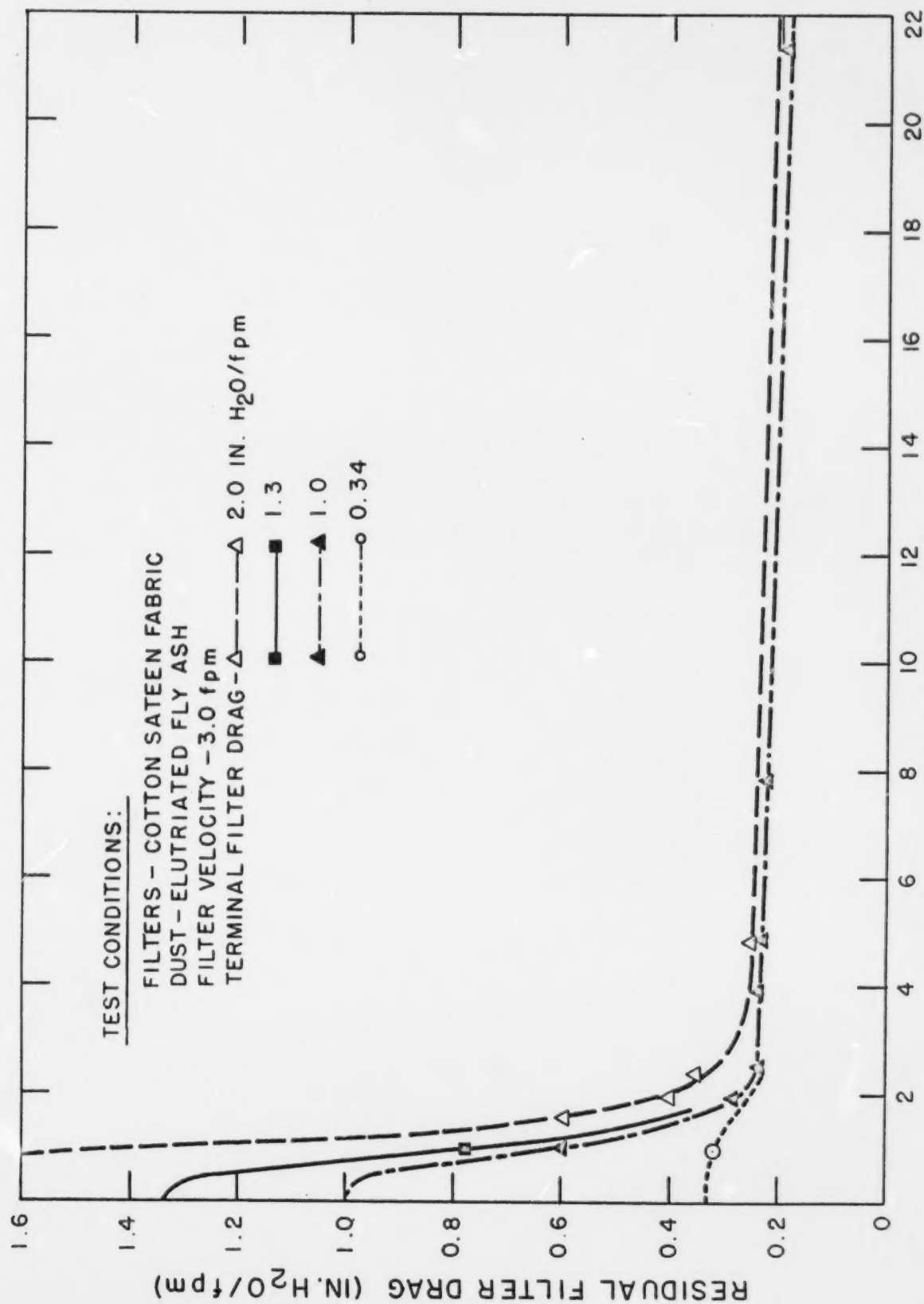
Figure 4 shows the relationship between filter capacity and maximum acceleration for the test conditions shown. It can be seen in this figure that increasing acceleration up to about 3.0×10^6 in/min/min resulted in a rapid increase in filter capacity, while increases beyond this value were small. For the test conditions shown, therefore, an acceleration of 3.0×10^6 (in/min/min) is considered a practical optimum in terms of cleaning effectiveness. The same optimum acceleration produced minimum filter drag, as shown in Figure 5.

In developing Figures 4 and 5 it was necessary to use capacity values obtained with N_w strokes and residual drag values obtained with N_g strokes, as interpreted from curves similar to those of Figures 2 and 3, because the independent variables of amplitude and frequency influenced the transmission of motion as well as shaker acceleration, as explained in the next section. The fact that the same optimum acceleration was required to obtain limiting values for the response



EFFECT OF SHAKER ACCELERATION ON FILTER CAPACITY

FIGURE 4



EFFECT OF SHAKER ACCELERATION ON RESIDUAL FILTER DRAG

FIGURE 5

variables (although durations were different) indicates that the forces associated with this acceleration were able to produce motion over the entire filter area, provided sufficient time was allowed for the motion to develop. Conversely, for accelerations below 3.0×10^6 (in/min/min) the motion developed did not affect the entire filter area.

Transfer of Motion

In practice, the number of strokes required to reach N_s and N_w will depend on the effectiveness with which motion is transmitted to the filter and over the filter surface. Data analysis for the fly ash-cotton combination has shown that shaker amplitude was influencing in this respect, as shown in Figure 6, for N_s values. It can be seen in this figure that increased shaker amplitudes decreased the number of strokes required to reach N_s . The smooth curve obtained for data at different shaker frequencies, as well as the coincidence of points for frequencies of 315 and 494 cpm further indicates that the transmission of motion was independent of shaker frequency.

The number of strokes required to reach maximum capacity was apparently affected by amplitude in a similar manner. There are indications, however, that N_w was also influenced by shaker frequency, but data obtained were not sufficient to develop clear relationships in this area. Frequency, then, was the most important of the two variables in regard to acceleration, but amplitude was more important relative to the transmission of motion.

Different dusts on the same fabric appeared to have little influence either on N_s values or on residual drag. Figure 7, for instance, shows the effect of cleaning time on residual drag for fly ash and electric-arc furnace fume on cotton

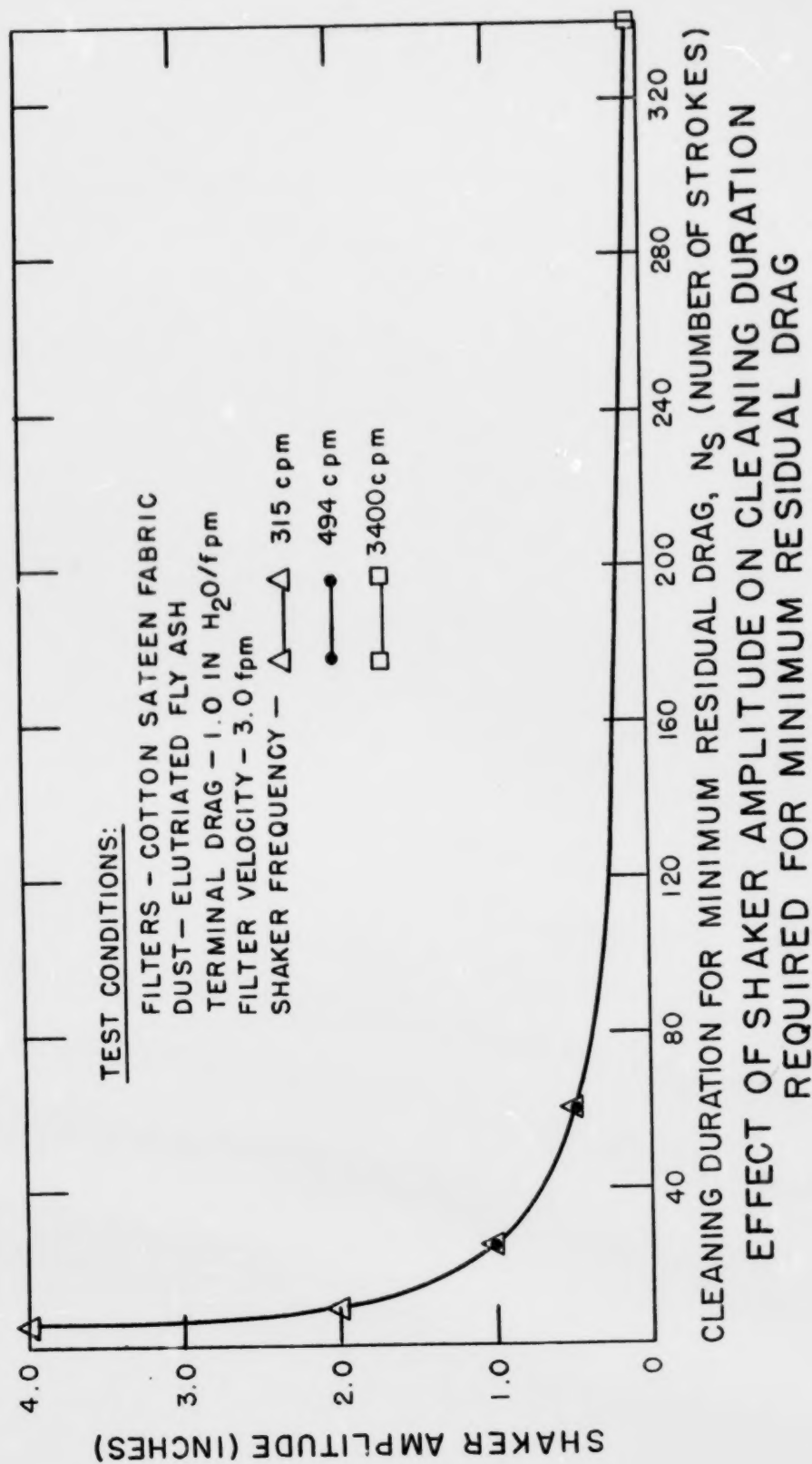
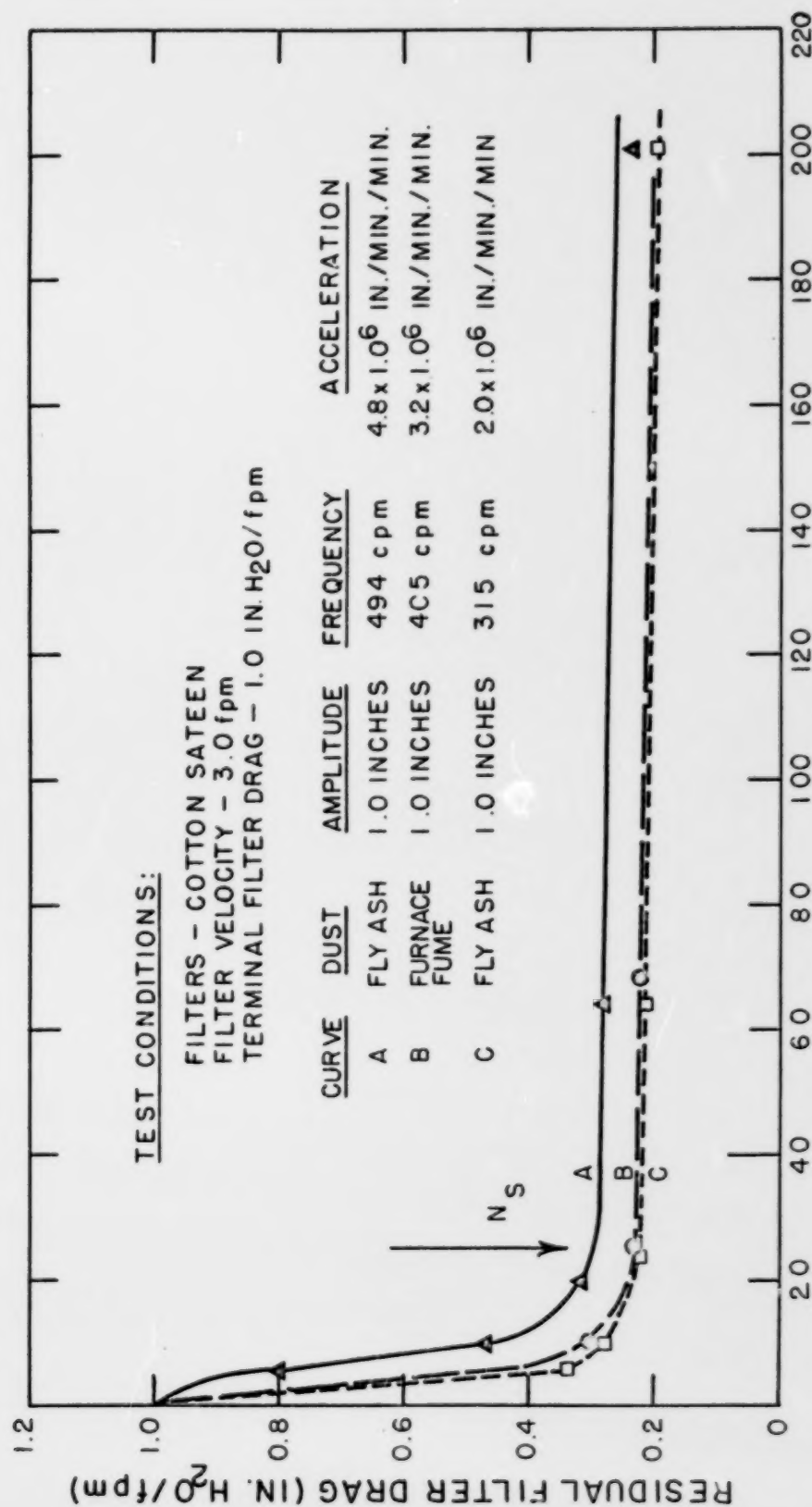


FIGURE 6



CLEANING DURATION (NUMBER OF STROKES)
 EFFECT OF DUST ON "RESIDUAL DRAG - CLEANING DURATION"
 RELATIONSHIP

tubes. The horizontal shake in each case was 1 inch in amplitude, but acceleration was different because of different shaking frequencies. It can be seen in Figure 7 that N_s was the same in each case, and that the residual drag obtained with the furnace fume falls within the range predicted by the fly ash data. Considering the differences in properties of the two materials it is not unlikely that these results would hold true for other dusts as well. It is quite possible, therefore, that N_s could be used to measure the influence of transmission factors (fabric weight, tube geometry, etc.) on cleaning, and that an investigation of this nature would be applicable to any dust. Further, it is possible that absolute values of residual filter drag may be a property of a system independent of type of dust, at least when the shake used has an acceleration equal to or greater than the optimum acceleration for the system being considered. Data of this nature would be extremely useful in predicting operating filter pressure differentials.

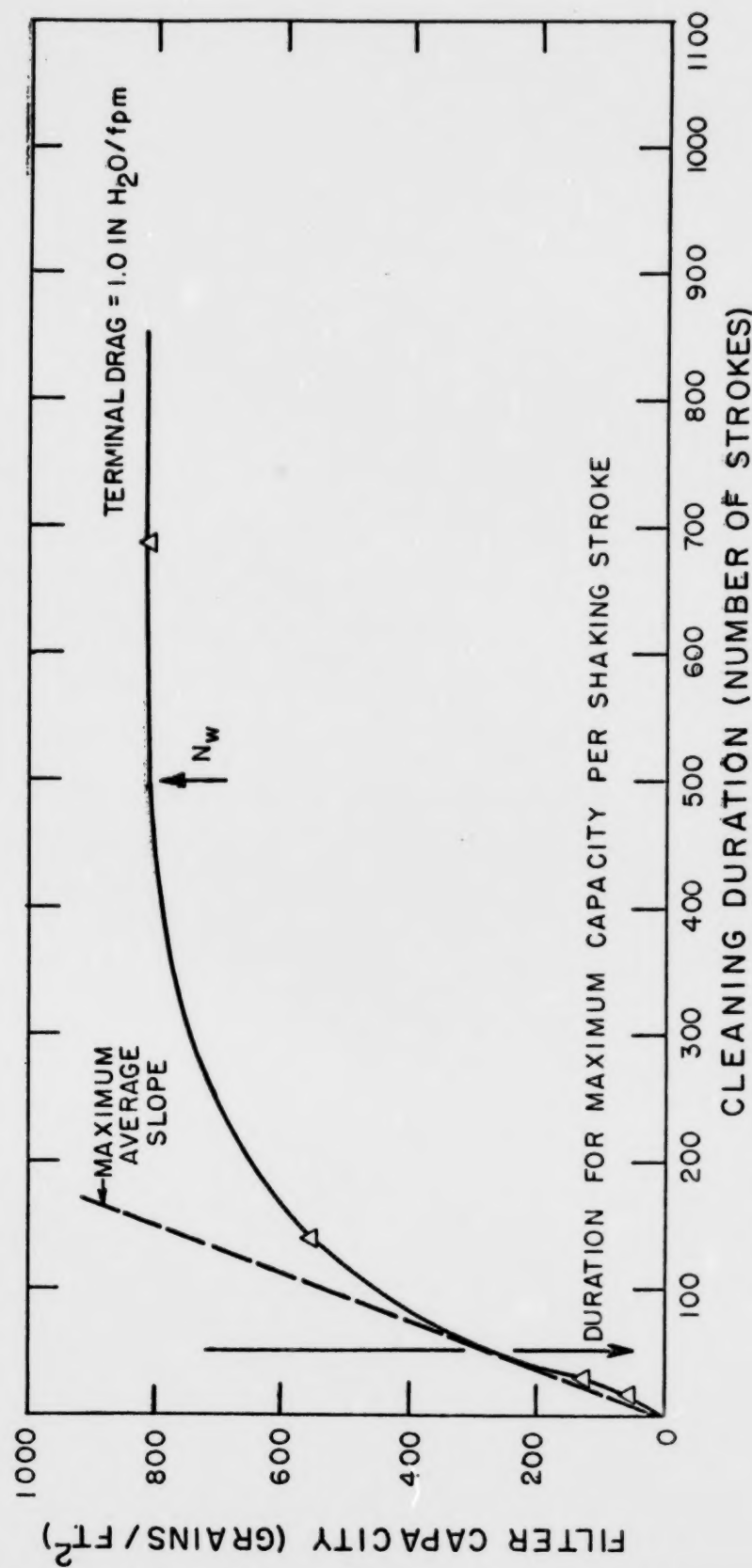
Practical Application of Results

The foregoing relationships invite further study in terms of practical applications. For example, it has been mentioned that the influence of factors affecting the transmission of motion may be directly related to N_s , and it has been shown that longer shaking amplitudes might be desirable since they favor the transmission of motion. A definitive conclusion cannot be reached, however, until the influence of amplitude on filter wear is known.

Another application of the data is related to reducing filter wear for a given shake by minimizing the total number of strokes applied over a period of time. The cleaning duration which will achieve this effect can be found by drawing a line from the origin and tangent to the curve of a "capacity vs. duration" relationship,

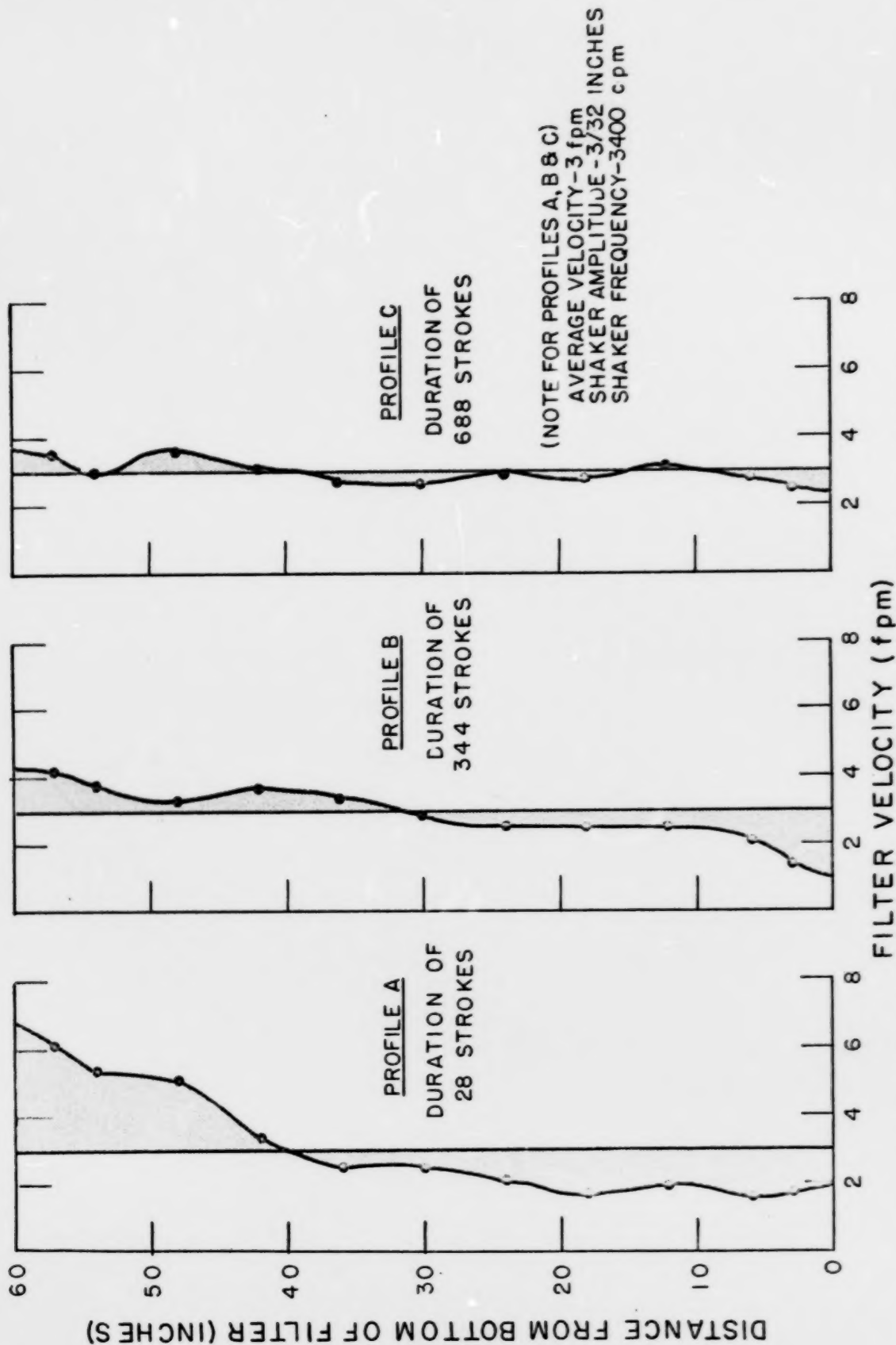
as shown in Figure 8. The duration at the point of tangency will allow the most dust to be filtered per shaking stroke, such that the total number of strokes utilized over a period of time (say one week) will be significantly less than the total number used with a duration of N_w strokes. The total amount of dust collected over this period and maximum filter drag for each cycle would be the same in both cases. For the illustration shown, the total number of strokes required for operation at this optimum condition for a 40-hour interval would be approximately one-third the number required if N_w strokes were used for each cleaning period.

In practice, operation under this condition probably would produce a residual dust cake less uniform than that after N_w strokes, so that significant aging (gradual increase in residual drag with time) may complicate operation in this region and filter efficiency may be affected in certain cases. The extent of such nonuniformities can be seen by considering local velocities of filtration as shown in Figure 9. These data were taken while determining the curve of Figure 8 and indicate the degree of nonuniformity that existed after several cleaning durations. For instance, the profile after cleaning with 28 strokes shows velocities on the order of 5 to 6 fpm through the upper portions of the filter, while the profile after cleaning with 688 strokes shows a uniform velocity of 3 fpm over the entire filter surface. The former situation indicates that the shaking motion was effective in reducing local filter drag only at the top of the bag; hence, velocities there are higher than average. Repeated operation with this shake would result in a gradual build-up of drag at the bottom of the filter and a gradual increase in the effective drag of the unit. This type of drag increase would not occur when operating with a duration of 688 strokes because the entire



DETERMINATION OF DURATION FOR MAXIMUM CAPACITY
PER SHAKING STROKE

FIGURE 8



LOCAL FILTER VELOCITY AFTER VARIOUS CLEANING
DURATIONS WITH THE SAME SHAKE

FIGURE 9

filter area would be affected by the shaking motion. A further discussion of nonuniformities along the length of filter tubes can be found in the literature.⁽³⁾ The local filter velocities shown in Figure 9 were measured by means of a velocity probe, the details of which have been published.⁽⁵⁾

Figure 5, which contains several curves representing residual drag as a function of acceleration and terminal drag, has certain practical implications. These data indicate that in the region below the optimum acceleration residual drag was dependent on terminal conditions, while in the region above the optimum acceleration it was practically constant. In other words, changes in conditions such as increased cycle times or increased dust concentrations, which would increase the terminal drag of a unit, will increase residual drag if the acceleration of the shake is below optimum for the system. Also, if a unit is operated on a time-cycle and the acceleration is below optimum, both residual and terminal drags will increase from cycle to cycle until the drag reduction during cleaning equals the drag increase during filtration. This effect will be in addition to any other normal increases associated with an approach to equilibrium. Assuming that cleaning duration is in excess of N_s , a reduction in residual drag can be accomplished only by increasing acceleration. This type of phenomena may explain the results reported by Lemke, et al,⁽⁶⁾ wherein the residual drag of two pilot-plant filter units, operating on a timed cycle, increased gradually over a period of time. The increase was of such an extent that vigorous hand shaking was periodically required to maintain reasonably low filter pressure differentials. The vigorous shaking by hand, then, was comparable to increasing the acceleration of the shaker. It would seem possible, therefore, that a dependence of residual

drag on terminal conditions may be a general indicator of insufficient acceleration, and that the region of operation (i.e., above or below the optimum acceleration) may be determined by varying filtration times and monitoring the effect of such changes on residual drag.

Conclusions

The most important aspect of this research is that correlations exist between variables which are a measure of applied forces and the resulting filter cleaning effectiveness. The principal relationships demonstrated are as follows.

1. A well-defined limit will exist beyond which increased shaking with a given shaking stroke will not significantly contribute to further cleaning.
2. Filter capacity and residual filter drag are a function of shaker amplitude and the square of shaker frequency (maximum acceleration of bag cap) but again a well-defined limit exists beyond which increases in these factors will not result in further cleaning.
3. Shaker amplitude has an influence on the number of cleaning strokes required for a given degree of cleaning. This influence is independent of its effect on the maximum acceleration of the shaking stroke.
4. A relative measure of the influence of factors affecting the transmission of shaking motion can be obtained by considering cleaning durations required to produce minimum filter drag.
5. For any given shaking arrangement there will exist a cleaning duration which will produce the least bag wear over a period of time.

It can be said, therefore, that a potential exists for increasing the effectiveness of most mechanical shaking apparatus. Individual considerations, such as filter wear, also will help to determine the cleaning conditions selected. Additional studies should facilitate the design, selection, and optimization of shaking devices such that less costly fabric filter units will result.

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